Chapter 3

Land Use and Land Cover (LULC) Change in the Boconó River Basin, North Venezuelan Andes, and Its Implications for the Natural Resources Management

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Additional information is available at the end of the chapter

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1. Introduction

Land Use & **Land Cover (LULC)** have been historically permanently subject to biophysical and anthropogenic forces which induce changes in different structure-levels and space-time scales, and modify the energy and water exchange of the soil-vegetation-atmosphere system; such modifications become globally significant through their cumulative effects, so it would be particularly hazardous for food production and food security [1] [2] [3]. Thus, Land Use & Land Cover (LULC) changes are simply the most conspicuous changes in cultural landscapes worldwide [4] [5] [6].

Particularly the tropical regions have undergone dramatic Land Use changes in the last few decades, and these changes are the effect of an equally large number of local causes and factors, highlighting a complexity that tends to defy easy generalizations [7] [8] [9] [10] [11].

Many hydrological systems of the tropical regions are relatively densely populated, with relatively high rates of population growth, which has serious implications in the relationships between people and environmental services [12]. In mountainous regions, mostly poor people are settled in steep hillsides (slopes above 15%), usually practicing a smallholder farming system with agricultural production in small parcels for subsistence purposes, as well as shifting cultivation and slash & burn agriculture, which represent a pressure over natural resources in areas which are ecologically fragile and environmentally sensitive. About 25 to 30% of Central America and northern South America consist of mountainous areas where the conditions above mentioned are quite common [13]. Thus, the dynamics of natural resources use in river basins and watersheds across the mountain regions in the tropics are determined by three factors: environmental, social and economical conditions [4] [9] [12] [14] [15].

According to [8], the LULC changes have a notorious impact on climate, at local and regional levels, due to the modifications in the carbon cycle, the local evapotranspiration patterns, as well as precipitation regimes. This fact justifies many concerns about the implications that the LULC changes could have in the water resources, particularly in the hydrological regimes worldwide. These concerns have been motivating the analysis of the relationships between the LULC changes and the hydrological regimes (river flows, runoff dynamic, floodings, water depletion, etc) in a spatial-temporal perspective. Some examples of these includes: [16 - 31].

Certainly, these are valuable experiences to deal with such a complex task; however, there are still many gaps in this process to be solved, and many questions to be answered. Moreover, many of these experiences are all spatially confined to temperate regions, where biophysical as well as socioeconomic conditions are particular. Tropical ecosystems are very different from their counterparts in higher latitudes. They have different geological and evolutionary histories, and different climatic extremes and dynamics. The number of interacting species is typically much higher in tropical ecosystems, including streams networks also, and the interactions are often more complex [9]. Social, economical and political conditions in tropical rural areas are also very complex; thus, the poverty, depressive local economies, instability and lack of plans and investment programs are always current, and usually such complex realities and the collateral relationship has not been well studied so far. Thus, the knowledge remains still weak and the lack of information about local and regional environmental dynamic is remarkable [11] [14] [15] [32] [33] [34] [35].

The river basins are subject to constant processes of change, so the state and the structure of river landscapes and land resources are primarily determined by the type and intensity of the utilisation of the ecological, economic, social or cultural functions provided by the river systems. The new paradigm recognize the river basins as complex, ecological and interactive systems, which means that the integrated water resource management follows the central themes of the **ecosystem approach** and of adaptative management; in fact, the WFD (Water Framework Directive) of the European Union, has adopted the "**ecosystem-oriented river management** " as central approach to be followed by the institution [36].

2. Problem description

The Andean region in Venezuela is considered the most important "**water resource-area**" in the western part of the country. The source streams of many important river systems in the country are located there, having a complex and intricate channel network, with the "**first order streams**" (the most important sources of fresh water in many regions worldwide) broadly dominating the landscape system. Due to the biophysical configuration and the attractiveness of the Andean landscapes, the region has been under anthropogenic impact from times before the arrival of the Spaniards. However, in recent decades that pressure has been gradually increasing, which eventually could have significant impacts on the natural resources basis, particularly water, forest and soils.

Located in the northern part of that region, the Boconó River Basin can be considered as a representative case of the complex dynamics characterizing the Andean hydrological systems. Having a total surface area of 1580 km^2 and a wide altitudinal range, the River Basin harbor many ecosystems ranging from the Sub-Andean Páramo in the upland areas, to the Savannah ecosystem downstream in the upper plains of the Llanos region. With an annual yield of 2,300 million m^3 and a very acceptable chemical quality, the Boconó River was included into the regional planning policies in the Seventies, in order to develop the water resources in the lowlands region, so that the Boconó – Tucupido Dam systems were built in the Llanos region, in order to generate energy, flooding control and for irrigated cropping also [37].

A very significant portion of the area is still under natural Land Cover types, like the **Tropical Montane Cloudy Forest (TMCF)**. This ecosystem has a paramount importance, not only in terms of their ecological richness, but also in terms of hydrological functioning, specifically for water yield. In such forests there is usually a net gain of water that comes from the "**horizontal precipitation**" or "**occult precipitation**" in form of wind-driven drizzle and fog [9] [38].

On the other hand, there are also numerous sparse rural settlements representing a huge potential for agricultural production of some crops like coffee and vegetables (potatoes, carrots, onions, beans and others). The high accessibility through an intricate network of rural and local roads makes it easier to promote the sparse settlement in sloping hillsides across the area, being a crucial factor which determines the LULC changes contributing to the intensification of some erosion and land degradation processes [39].

All these conditions acting together in a strongly integrated way, resulting in a complex situation in which the increasingly sparse population is making even more pressure on natural land cover types, particularly on the **Tropical Montane Cloudy Forest**, so that the conversion of LC into LU appears to be persistent and intense. The River Basin was declared in 1974 "Protected Area" in order to preserve the water resources [40], and the Guaramacal National Park was created in 1988, which cover the southeastern flank of the area. Both figures aimed to guarantee the conservation of the ecosystems, the biodiversity, and to ensure the water production [41].

Nevertheless, the area continues to show a trend respect to the anthropogenic pressure, so the agricultural frontier is even more extended, meanwhile the forested land cover types tends to be decreased, and some land degradation processes like erosion and sediment yield seems to be even more intense. This has severe implications for the biodiversity, but also affects substantially the hydrological dynamic through changes in local microclimates, changes in moisture regimes, that eventually could lead changes in the hydrological regimes, especially the seasonal flows, peak flows, as well as changes in the water quality.

2.1. Main goal

The main goal of this paper is to analyze the spatial dynamic of the Boconó River Basin during the Period 1988 – 2008, in terms of the main LULC changes and systematic transitions that have been occurring in the area under an ecosystem-oriented approach.

They were discussed in terms of the implications that such changes and transitions have for the natural resources management at the river basin level (watershed management). The results showed here are only a partial output of the still ongoing PhD project: "Spatial changes and hydrological dynamic of the Boconó River Basin, north venezuelan Andes", which is actually developed at the Eberhard Karls University – Tübingen, Germany.

3. The geographical context – study area

The study was focused on the upland part of the Boconó River Basin, located in the south-east part of the State of Trujillo, between the coordinates 09°11′40″ - 09°31′50″ N and 70°04′08″ – 70°22′53″ W, with a surface area of 537.62 km^2. The highest point in the Basin is 3400 m.a.s.l in the Páramo of Cendé, and the lowest point (outlet) is the confluence between the Boconó and Burate river (1100 m.a.s.l) (Fig. 1). The Boconó River drops from the north-east to the south-west, over a distance of approximately 57 km, having a mean runoff about 15, 55 m^3/sec [33].

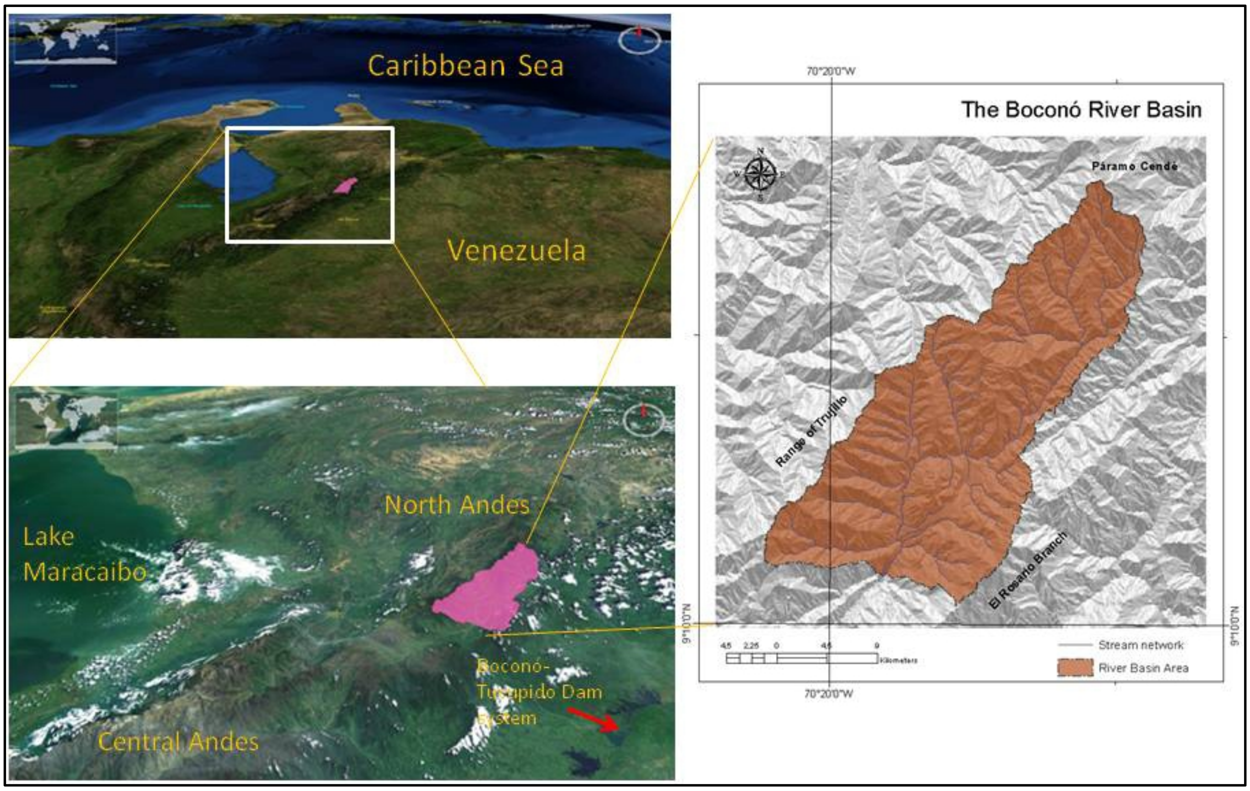

Figure 1. Location of the Study area

The area has a seasonally humid climate, having a wet period from April to October, and a dry period from November to March. Annual mean rainfall is about 1838 mm, and the annual mean temperature range from 19.7 °C to 21.5 °C [42]. The Basin has a relatively elongated form, and the drainage pattern is dendritic with a tendency to be rectangular, due to the intense tectonic activity [37].

The catchment is located within the tectonic axis formed by the Boconó Fault, which is the most important structural feature of the Venezuelan Andes [37]. The Fault cross longitudinally the river, separating the metamorphosed crystalline rocks in the north portion, from those less metamorphosed in the south part [33]. The basin has a massive and strongly dissected topography, so that the topographic conditions are quite complex and varied, determined by different landforms like: structural risks, erosion risks, structural escarpments, hillsides and alluvial accumulations, and a mean slope which range between 35 – 40% [43].

The lithological framework is generally highly jointed, due the tectonic dynamic, and the rocks basically correspond to the formations: Iglesias Group (gneisses and schist), Sierra Nevada (granites), Mucuchachí (Shale and phyllites) and Palmarito (shale and marl) [44]. Soils are in general relatively deep, with textural classes ranging from clayed to sandy loam, being Ultisols, Inceptisols and Alfisols the most important and representative taxonomic categories in the area [45].

The altitudinal gradient (2300 m.a.s.l) and the climatic conditions, particularly the intense rainfall regime, lead to the existence of the Tropical Montane Cloudy Forest, which cover the 44, 6 % of the total surface. Other important ecosystems in the area are: sub-montane forest, grass, sucessional shrubland, schrub and sub-alpine Páramo. These categories of land cover coexist also with specific land use types, which are very importance not only in economical terms, but in social and cultural perspectives also [46]. Shifting cultivation is located mostly in upland areas, where slash and burning are usual tasks. Conventional agriculture is also developed in lower parts and quaternary landforms, in some cases under irrigation. Coffee plantations are very usual between 800 and 2000 m above sea level, occupying an important portion of the Sub-montane forest. In a small proportion, the extensive grazing shows a moderate development, being usually spatially confined to the low parts and the quaternary landforms [42]. Finally, the 1, 6 % of total surface is occupied by urban use, being the Boconó city the most important urban system in the area.

4. Methodological approach

In order to achieve the purpose of this project, a methodological approach combining remote sensing methods with spatial and multi-temporal analysis in GIS in an interactive way was implemented. At first, the study area was delineated from the SRTM data set (90 m spatial resolution) using the open source GIS software SAGA (System for Automated Geoscientific Analysis), in order to build the Digital Elevation Model (DEM), and also to prepare the basic thematic maps (Topography, Slope, Aspect, Drainage Network). Based on the structure pointed out by [47], the LULC mapping process was done in three main straightforward steps, as follows:

4.1. The pre - processing

Three time-points were defined in order to analyse the LULC dynamic in the river basin: T0 (1988); T1 (1997); and T2 (2008). For each time-point a group of LANDSAT TM scenes corresponding to missions 4, 5 and 7 were compiled from USGS LANDSAT Archive and the Institute of Geography (IGCRN) – ULA (Venezuela), which were considered suitable to the research requirements. The compilation process was quite difficult because the study area is frequently covered by dense clouds, especially during the rainy season. It means that the cloudiness and fog represented a challenge to deal with into the classification process, leading to compile additional scenes for special processing. Thus, the compiled scenes were classified in two groups: "**pilot**" scenes and "**control**" scenes. The first group included the main scenes to be classified for each time-point to be considered in the multi-temporal evaluation: 1988, 1997 and 2008, respectively. The second group were used as control images for the optimization of the classification for the first group, in order to improve the clustering processing in those areas covered by cloud, fog and shadows.

All the LANDSAT scenes compiled were pre-processed individually to make the geometric and radiometric correction, as well as the enhancement of some elements like brightness, contrast, haze reduction and equalization, in order to improve the image quality. All these processes were carried out interactively.

4.2. The LULC classification/analysis process

The classification process was developed through a semi – supervised method, following a multi – level clustering for a multi – class segmentation of the scenes. The scenes were separately classified, a procedure considered highly flexible and extensively used in the past, with good results reported [47].

At the first level the scenes were classified through an unsupervised method using the "**hyperclustering approach**", a simple and relatively common approach to classify multiple LANDSAT scene mosaics. This classification approach generate many hyperclusters from the image data available by testing for within – cluster heterogeneity; then the hyperclusters can be merged into a smaller number of more reasonable groups which may resemble homogeneous classes, and finally label the resulting classes as spatial features of interest according to a pre-determined map legend or class hierarchy [48]. The process was done using the algorithm K-means available within the ISODATA decision-rule. In this case, the method was applied using 50 clusters to be classified after 24 iterations through the unsupervised approach (previous tests using 80 and 100 clusters, showed not many differences in the effective separation of the classes). The amount was then though reasonable to manage by the interpreter, and appropriate to differentiate the LULC classes in the study area.

Two groups of clusters were then identified: "**pure clusters**" representing categories with unique spectral signal; and "**mixed clusters**", having two or more categories with similar spectral signal, which is normal because LANDSAT imagery for tropical forest regions display minimal band separability among vegetation types, so that different types of categories can be usually difficult to separate [49]. The "**mixed clusters**" were prone to a second - level classification process. They were separated from the scene through masking process, and after that they were submitted into a second clustering process, using supervised and unsupervised methods. Thus, the classes were correctly separated from the others. During the second – level classification, the clouds, fog and shadows were appropriately separated from other classes. They were used as mask scenes in order to cut the control images through spatial analysis, and finally they were processed like the "**mixed clusters**", in the same way above described.

4.3. The product generation process

All the clusters were merged to form twelve final classes using the grouping process. Additionally, a spatial modelling process was done in order to make the altitudinal differentiation of the LC in the river basin, defining the Land Cover categories in an ecological sense, following the ecosystem approach. For this purpose the DEM was combined with the classified images using the ecological criteria from Sarmiento & Ataroff in [50]. Thus, the Land cover categories delineated are virtually "ecosystems units". The classified scenes were finally filtered and exported to GIS software for the mapping creation and display processes.

The classifications were validated using conventional methods, depending on the availability of the reference ancillary data. For the T0 classification, only a land use map for 1980 was available in a non digital format. This map was then used as a reference source for the validation. A total of 255 validation points corresponding to reference pixels were randomly selected using the "**stratified random**" sampling method. They were interactively compared with the digital reference map, and the results were stored in the Accuracy Assessment Cell Array (software ERDAS 9,3), which is simply a list of class values for the pixels in the classified image file and the class values for the corresponding reference pixels [51]. The tool finally calculated the error matrix and the corresponding basic statistics, including the Kappa Coefficient, which were listed in the Accuracy report. For T2, a field validation process was driven, combined with validation points defined using Quickbird high resolution scenes available on the "open source" software GOOGLE EARTH, through the same process described for the T0 scenes. Finally, the T1 Classification was validated using the maps for T0 and T2, defining validation points basically in areas considered persistent across the time-period.

4.4. Multi-temporal evaluation of LULC changes in the Boconó River Basin (Post classification)

The multi-temporal evaluation process was conducted through spatial analysis in GIS. Hence, paired overlay was done in order to detect the changes occurred during the time-period considered. The Matrix operation used in this case allows two thematic images or vector files of different years to be compared [52]. This tool allowed to cross two different maps corresponding to the same area, in order to differentiate the changes occurred between the time-points. The resulting class values of a matrix operation are thus unique for each coincidence of two input class values described by rows (input layer 1) and columns (input layer 2) [53]; hence, the process produce two type of results: Maps which can illustrate the changes in a spatial context (land cover change map); and a **cross-tabulation matrix** containing the differences in area for the different classes.

The **cross-tabulation matrix**, also denominated "**transition matrix**" follows the format displayed on Table 1. The rows display the categories of time 1, and the columns display the categories of time 2. Entries on the diagonal indicate persistence in the landscape between the time-period, meanwhile the entries off the diagonal indicate a transition from category "*i*" to a different category "*j*" [54].

	Time 2				Total Time 1	Loss
Time 1	Category 1	Category 2	Category 3	Category 4		
Category 1	P_{11}	P_{12}	P_{13}	P_{14}	P_{1+}	P_{1+} - P_{11}
Category 2	P_{21}	P_{22}	P_{23}	P_{24}	P_{2+}	P_{2+} - P_{22}
Category 3	P_{31}	P_{32}	P_{33}	P_{34}	P_{3+}	P_{3+} - P_{33}
Category 4	P_{41}	P_{42}	P_{43}	P_{44}	P_{4+}	P_{4+} - P_{44}
Total Time 2	P_{+1}	P_{+2}	P_{+3}	P_{+4}	*1*	
Gain	$P_{+1} - P_{11}$	$P_{+2} - P_{22}$	$P_{+3} - P_{33}$	$P_{+4} - P_{44}$		

Table 1. General cross-tabulation matrix for comparing two maps from different points in time

Starting from the matrix-values, the Gain (G_{ij}) was calculated through the difference between the total value for time 2 (P_{+j}) and the persistence (P_{ij}), using the Eq 1:

$$G_{ij} = P_{+j} - P_{jj} \tag{1}$$

On the other hand, the Loss (L_{ij}) was the difference between the total value for the time 1 file (P_{j+}) and the persistence, using the Eq 2:

$$G_{ij} = P_{+j} - P_{jj} \tag{2}$$

The swapping (S_j) between the categories was calculated as two times the minimum value of the gains and losses, through the Eq 3:

$$S_j = 2 \text{ x MIN} \left(P_{j+} - P_{jj}, P_{+j} - P_{jj} \right) \tag{3}$$

The total change for each category (C_j) was the sum of net change (D_j) and the swapping (S_j), or the sum of gain and loss (Eq 4):

$$C_j = \left(D_j + S_j \right) \tag{4}$$

In order to intend a more detailed analysis of the LULC changes, particularly the systematic inter-category transitions, the methodology proposed by [54] was applied, which analyze the off-diagonal entries to identify systematic transitions of land change for a given landscape´s degree of persistence. For that, the transitions must be interpreted relative to the sizes of the categories, leading to define the gain/loss that would be expected if the gain/loss in each category were to occur randomly [54]. The randomly expected gains for each category were calculated using the Eq 5:

$$Gij = \frac{(P+j-Pjj)x\ Pi+}{1-Pj+} \quad (5)$$

In this case, the gain as well as the proportion for each category at time 2 is considered fixed, distributing the gain across the other categories according the relative proportion of the other categories in time 1. The procedure to calculate the randomly expected losses for each category is quite similar to those explained above, using the Eq 6:

$$Lij = \frac{(Pi+ -Pii)x\ P+j}{1-P+i} \quad (6)$$

As in the gain, the equation assumes that the loss of each category is fixed, and then distributes the loss across the other categories according to the relative proportion of the other categories in time 2.

Finally, the systematic transitions were identified trough a comparison between the observed and expected values for gain and loss, for each category.

5. Results & discussion

Twelve (12) LULC categories to be analyzed were identified in the Boconó River Basin for T0, T1 and T2 classifications. The Table 2 display the LULC categories, each with the corresponding identity-code, designation, as well as a brief description. The results showing the accuracy and the Kappa Coefficient for the three time-points are displayed on Table 3. Two important clarifications must be here pointed out:

1. - The Category Open-cleared Forest (Oc-F) correspond to the lower sectors of the Tropical Montane Cloudy Forest (Tmc-F), which are prone to a clearcutting process for logging and wood extraction, eliminating partly the canopy of the tallest forest species; the clearing alter greatly the phenological structure of the forest, resulting in a very specific and different spectral signal respect the climax or undisturbed forest. They were conveniently considered separated categories for practical purposes inherent to the research goals.

2.- Coffee plantations constitute an important land use practice in the area; however, during the classification process the plantations (shade coffee) usually showed a very similar spectral signal as the Sub-montane Forest, which is the ecosystem where these plantations are usually located. They couldn't be effectively separated at this resolution level, and more detailed remote sensing material for the study area was no available. For that reason the coffee plantations were necessarily combined with the Category: Sub-montane Forest (Sm-F).

5.1. General quantification of the change

The corresponding surface values for the time-points analyzed (T0, T1 and T2), are gently resumed on Table 4. An overview of the differences among the period, lead us to set up a basic differentiation between the LULC categories in three main groups as follow:

a. LULC categories losing surface: basically the natural LC like forest (Tmc-F, Oc-F, Sm-F) and Grass (Gr-L) were included here. All of them show a decreasing trend between T0 and T2 (except Gr-L, which experienced a light increase between T1 – T2). The Tmc-F and Oc-F had a reduction of 3530, 43 ha between T0 – T2, representing the 12, 8 % of the total for the two categories combined in 1988. The reduction of the Sm-F in the river basin was more dramatic, losing the 43, 1% of the surface area respect to 1988, that is, 3244, 59 ha. On the other hand, Gr-L loosed 412, 11 ha between T0-T1, and slightly recovered 85, 05 ha in the next period, losing a total of 327, 06 ha (9 % of the total in 1988).

Category	Identity-Code	Designation	Description
1	Tmc-F	Tropical Montane Cloudy Forest	Multilayered forest with a very complex structure. The vegetation is dominated by evergreen Trees whose crowns may rise up to 35 m height, bearing a large number of different epiphytes (> 100 species). The forest may have accounted for an average of 100 tree species per hectare.
2	Oc-F	Open – Cleared Forest	In fact this category corresponds to the lower sector of the Tropical Montane Cloudy Forest, which is undergoing a clear-cutting process. There are evidences of selective clear cutting of tree species, so that the forest presents a less dense and more open canopy, as well as the presence of successional vegetation.
3	Sm-F	Sub-Montane Forest	Multilayered forest with a complex structure. During the short dry season (1 – 3 months), the upper – canopy trees throw a lot of its leaves, having a reduced foliage; although the lower trees and shrubs are mostly evergreen. The canopy reaches up from 20 to 30 m height; however some individuals trees can reach up to > 40 meters. The coffee plantations, specially the coffee planted under shadow belong also to this category.
4	Schr	Schrub	Open forest with dense vegetation, which can reach a height of 3 – 6 meters. Corresponds to the transitional zone between the High Montane Cloudy Forest and the Sub-andean Paramo.
5	Gr-L	Grassland	Areas with natural mixed herbaceous vegetation ad grass. The vegetation is generally dense and can reach 2 meters height.
6	Cro-L	Cropping area	Area under crop systems typologies diverse as horticulture and coffee without shadow.
7	Sa-P	Sub-andean Páramo	Special ecosystem existing in the whole Andean region, consisting mainly of grass, ground rosettes, dwarf shrubs cushion plants and conspicuos giant rosettes like Espeletia and Puya. However, the vegetation vary greatly depending on the altitude, humidity and other environmental factors.
8	Gr-An	Grassland (anthropogenic)	Areas of cultivated grasses and / or pastures established for extensive grazing and cattle
9	S-Shr	Successional shrubland	Areas with successional vegetation being in regeneration process after the clear cutting, or after they were cultivated. The vegetation usually has low hight and variable density.
10	Ero-L	Eroded Soil	Bare soil surface, prone to the direct action of erosion agents.
11	Fl-P	Flooding Plain	Area occupied by the river bed, usually having low slope where the river can be horizontally expanded.
12	Ur-U	Urban Use	Area occupied by the Boconó city, as well as the towns San Miguel and San Rafael. Basically corresponds to a residential, commercial use and associated services.

Table 2. Land Use / Land Cover (LULC) Categories identified in the Boconó River Basin.

Indicator	T0 (1988)	T1 (1997)	T2 (2008)
Producers Accuracy	87,46	85,02	91,53
Users Accuracy	87,62	82,90	91,67
Total Accuracy	87,35	82,59	88,80
Kappa Coefficient	0,79	0,79	0,87

Table 3. Main results obtained in the Accuracy assessment for the T0, T1 and T2 classifications.

LULC Categories	1988 (T0)	1997 (T1)	2008 (T2)	Dif T1-T0	Dif T2-T1	Dif total T2-T0
	Area (ha)	Area (ha)	Area (ha)			
Tropical Montane Cloudy Forest	24573,78	23676,12	22493,97	-897,66	-1182,15	-2079,81
Open-cleared Forest	2973,51	1648,8	1522,89	-1324,71	-125,91	-1450,62
Sub-Montane Forest	7523,1	6224,13	4278,51	-1298,97	-1945,62	-3244,59
Scrub	1142,37	1199,88	1277,73	57,51	77,85	135,36
Grasland	3662,82	3250,71	3335,76	-412,11	85,05	-327,06
Sub-andean Paramo	1114,2	1117,71	1114,47	3,51	-3,24	0,27
Grassland (Anthropogenic)	1280,34	1181,16	2832,03	-99,18	1650,87	1551,69
Cropping Area	2202,84	2330,46	2867,4	127,62	536,94	664,56
Eroded Land	28,62	27,27	39,87	-1,35	12,6	11,25
Urban Area	433,98	729,18	865,26	295,2	136,08	431,28
Flooding plain	234,9	391,95	293,76	157,05	-98,19	58,86
Sucessional Shrubland	8591,67	11984,76	12840,75	3393,09	855,99	4249,08
Total	53762,13	53762,13	53762,13	-	-	-

Table 4. LULC evolution during the considered period

b. LULC categories gaining surface: they are basically the human-induced types of land cover categories (Gr-An, Cro-L and Ur-U), as well as the categories: Schr and S-Shr. They increased progressively during the period, except Gr-An, which experienced a decrease in T0 – T1; however, the evident increase experienced during T1-T2 justify the inclusion of the category in this group. Gr-An and Cro-L combined, gained 2216, 25 ha, representing an increase of 63, 6 % of the agriculture in the river basin respect 1988. The Urban use (Ur-U) experienced a dramatic increase during the whole period, gaining 99,36 % (431,28 ha) of the surface area that the category occupied in T0. Meanwhile, the LC category S-Shr experienced a big change, gaining almost 50% (49, 5%) of the surface area for T0; so it gained a total of 4249, 08 ha. respect 1988. During the period Schr category gained 135, 36 ha (12%) respect to T0.
c. Relatively stable LULC categories: here are included the rest of the LC categories: Sa-P, Ero-L and Fl-P. These categories showed a similar pattern during the whole period, in which they loosed and gained surface, but maintaining its proportionality respect the rest of the LULC categories. The Fl-P gained 157, 05 ha (67%) because of the flooding events occurred during the T0-T1. But in the second time-period it loosed 98, 19 ha to other categories.

These basic groups illustrate the general trends for the recent evolution of the LULCC in the river basin. However, they are only the initial framework to understand the spatial dynamic in the study area, so they cannot reflect conveniently the spatial changes in a quantitative/qualitative way. The next section provides a more comprehensive and detailed description of the LULC categorical changes for the two time-periods, in terms of quantification, net change, swapping as well as inter-category transitions.

The Figure 2 show the spatial distribution of the changes in the Boconó River Basin, which occurred within the both periods: T0 - T1 and T1 – T2. In the first period the River Basin experienced a total change of 30,34%, which means that 16309,89 ha were affected by a kind of spatial change processes, meanwhile the 69,66% of the surface area (37452,24 ha) was accounted as persistent landscape or simply persistence. Thus, persistence dominates widely the landscape system of the River Basin, which is considered normal, because the persistence usually dominates most landscapes, including those where authors claim that the change is important and / or large [54].

[55] accounted 92% of persistence for natural land covers in Mexico; in the Atlanta metropolitan area (one of the USA´s fastest growing metropolises), there have been 75% persistence over the last 3 decades (Yang & Lo, 2002) in [54]. [56] determined a persistence of 94, 2% in the community of Madrid – Spain. [57] accounted 93, 3 of landscape persistence in the State of Mexico – Mexico. Finally, [30] also detected a persistence of 80, 5% in the Catamayo-Chira Basin (Ecuador – Peru).

Although the persistence dominates the landscape, as usual, the persistence value of the Boconó River Basin can be considered slightly lower in comparison with those values above mentioned. This fact is important to highlight, considering that the whole river basin is defined as "**Protected Area**", with a portion of the surface area also belonging to the **Guaramacal National Park**.

In the second period the total change was slight higher, with 18464, 7 ha affected by a type of change, representing the 34, 35% of the total area, and the persistence value descended to 65, 65 % of the total surface (35297, 46 ha).

As seen on Figure 2, the change have been occurring in the middle – lower part of the river basin, basically across the sloping dissected areas, the river valley and some extensive quaternary landforms located in the lowest part; in this case, the LULC categories coexist in a very intricate way, showing a very complex and strong patching effect, which is typical of landscapes where the categories are highly fragmented, originating the so – called "**chessboard effect**" or "**chessboard landscape**" [58].

5.2. Landscape dynamic: A more detailed view of changes in the River Basin

A more detailed analysis of the transition Matrix derived for the two combined time-periods (T0-T1 and T1 – T2), using the approach proposed by [54], lead to interpret the changes in a more detailed perspective, as follows:

5.2.1. Net change and swapping

The Table 5 resume the landscape dynamic observed for the period T0 – T1. S-Shr was the most dynamic category in the river basin during this period, having a total change which represent the 22,4 % (12037,6 ha), of the total surface. It showed also the highest values for gain and losses respect the rest of LULC. During the period, S-Shr gained 14, 35% of surface area, losing at the same time 8 % to other categories. This category has also the highest value for swapping (16,1 % of the surface area), which means that this LCC constantly experienced changes during the period, losing surface area to other categories and gaining at the same time area from other categories whose changed to this one. Thus, 72% of the change for this category occurred as swapping-change dynamic.

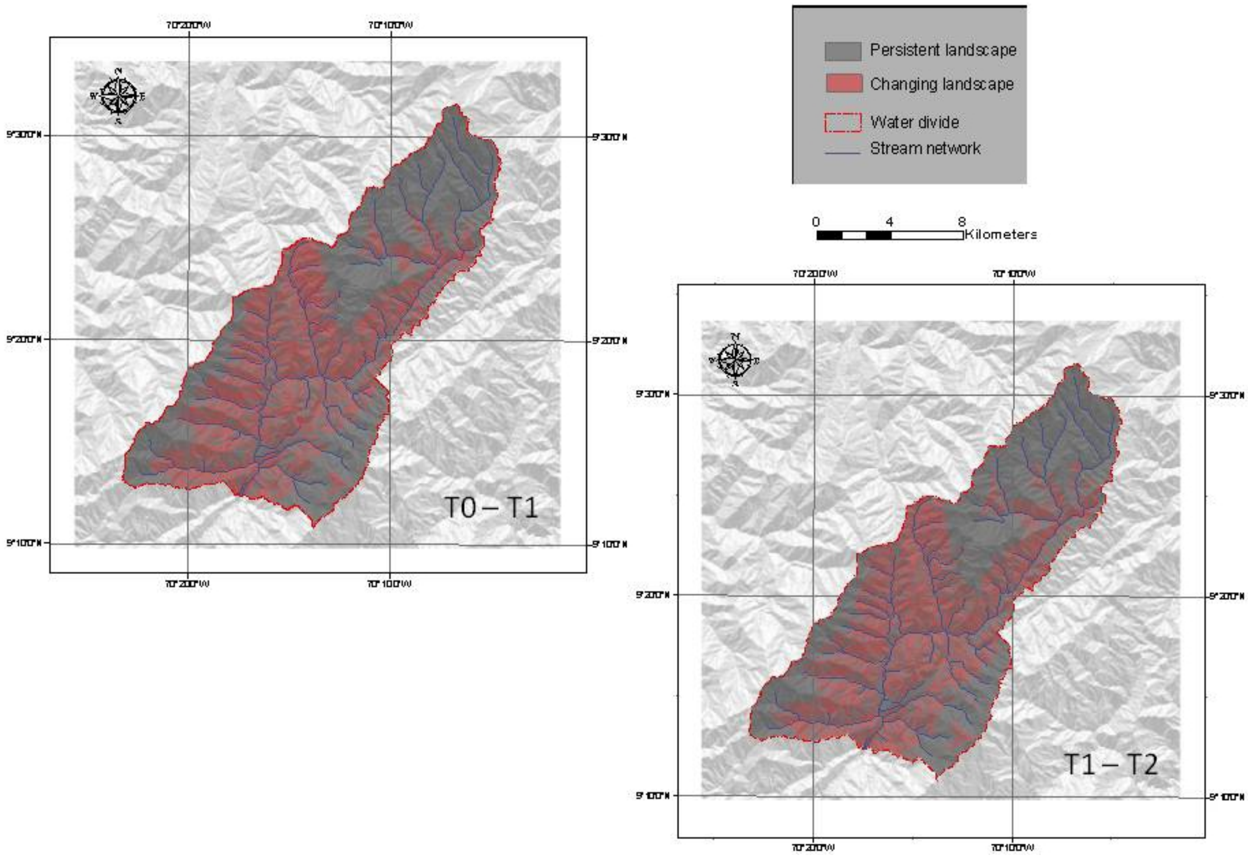

Figure 2. Persistence and changing area in Boconó River Basin

The second more dynamic category in the area was Sm-F, which experienced a total change of 4485, 51 ha, representing the 8, 3% of the total surface area. In this period Sm-F gained 1593, 27 ha (third highest value), which in many cases could represent an expansion of the shade coffee plantations in the area (included in this category). However, it lost 2892, 24 ha (second highest value) to other categories, representing an important reduction of the forested cover in the area. The category has the third highest value of swapping (3186, 54 ha), which suggest that the Sub-montane Forest also experienced a swapping-change dynamic.

The third category experiencing important changes in the period is the Oc-F, with a total change value of 3721, 41 ha, (7 % of the total area). The Open-cleared Forest gained the fifth biggest portion of surface: 1198, 35 ha, suggesting that the clearcutting and logging in the lowest part of Tmc-F were intense during the period. However, it lost 2523, 06 ha (third biggest amount) to other categories, showing that the clearcutting and logging was also intense within the category. A total of 2396, 7 ha (fifth highest value) were swapping-change dynamic for this category.

LULC Category	Gain		Loss		Total Change		Swap		Absolute value of net change	
	ha	%	ha	%	ha	%	ha	%	ha	%
Tmc-F	792,45	1,474	1690,11	3,143	2482,56	4,617	1584,9	2,948	947,66	1,669
Oc-F	1198,35	2,229	2523,06	4,693	3721,41	6,922	2396,7	4,458	1324,71	2,464
Sm-F	1593,27	2,963	2892,24	5,380	4485,51	8,343	3186,54	5,926	1298,97	2,417
Schr	58,86	0,109	1,35	0,003	60,21	0,112	2,7	0,006	57,51	0,106
Gr-L	1565,1	2,911	1977,21	3,678	3542,31	6,589	3130,2	5,822	412,11	0,767
Sa-P	7,29	0,014	3,78	0,007	11,07	0,021	7,56	0,024	3,51	0,003
Gr-An	1085,49	2,019	1184,67	2,204	2270,16	4,223	2170,98	4,038	99,18	0,185
Cro-L	1789,2	3,328	1661,58	3,091	3450,78	6,419	3323,16	6,180	127,62	0,237
Ero-L	13,59	0,025	14,94	0,028	28,53	0,053	27,18	0,052	1,35	0,003
Ur-U	295,92	0,550	0,72	0,001	296,64	0,551	1,44	0,004	295,2	0,549
Fl-P	195,03	0,363	37,98	0,071	233,01	0,434	75,96	0,142	157,05	0,292
S-Shr	7715,34	14,350	4322,25	8,040	12037,6	22,390	8644,5	16,080	3393,09	6,310
Total	16309,89	30,335	16309,89	30,339	16309,89	30,337	12275,91	22,84	4058,98	7,501

Table 5. Landscape Dynamic in the Boconó River Basin for the Period T0 – T1 (1988 – 1997).

The fourth position in terms of total change (3542, 31 ha), gains (1565, 1 ha), loses (1977, 21 ha) and swapping (3130, 2 ha), is for Grassland; the balance between gains and losses, as well the swapping value, suggest that this category has a strong interaction with other LULCC. The fifth changing category with a total change of 3450, 78 ha (6, 4 % of the total area) is Cro-L, suggesting that the cropping area also experienced important changes during the period. The category gained 1789, 2 ha, which is the second highest value for the period, losing also 1661, 58 ha (sixth value). With the second highest value (3323, 16 ha), Cro-L experienced also a swapping-change dynamic in the area.

Tcm-F is located in the sixth position of total changes, with a total value of 2482, 56 ha (4, 6 % of the total). The category gained 792, 45 ha (seventh value), but lost 1690, 11 ha; meanwhile, 1584, 9 ha were accounted as swapping-change. Finally, Gr-An showed the seventh highest change, with 2270, 16 ha (4, 2 % of the total area). It gained 1085, 49 ha and lost 1184, 67 ha, with a swapping value of 2170, 98 ha.

Despite of the dynamic above described the values for net change shows some differences among the positions between categories. Having the highest net value of 3393, 09 ha, the S-Shr remains as the most dynamic category for the period. The Oc-F had the second highest net change value (1324, 71 ha), and the third position was for Sm-F (1298, 97 ha). The Tropical Montane Cloudy Forest had the fourth highest net change value (947, 66 ha), followed by Gr-L (412, 11 ha), and the sixth position is for the category Ur-U, with a net change value of 295, 2 ha (most of the change in this category is net change, as usual), and a swapping value which tends to be cero. These values lead to affirm that the LCC and particularly the Forested LCC experienced the most important net changes in the river basin during this period.

The Table 6 resume the landscape dynamic for the second period T1 – T2. Some slight differences can be observed respect to the last period. S-Shr remains as the most dynamic category, with a total change value of 11750, 85 ha (22 % of the total area). It gained 6303, 42 ha and lost 5447, 43 ha. The 93% of the total value for this category (10894, 86 ha), occurred as swapping-change dynamic. Sm-F remains in the second position, with a total change of 3638, 88 ha (7 % of the total area). It gained less surface than in the last period (846, 99 ha), which is the seventh observed value for the period. Meanwhile, the losses remained high, having the second highest value for the period (2791, 89 ha). A total of 1693, 98 ha changed in a swapping-change form.

LULC Category	Gain		Loss		Total Change		Swap		Absolute value of net change	
	ha	%	ha	%	ha	%	ha	%	ha	%
Tmc-F	877,5	1,632	2023,74	3,764	2901,24	5,396	1755,0	3,266	1146,24	2,132
Oc_F	990,63	1,843	1113,21	2,071	2103,84	3,914	1981,26	3,686	122,58	0,228
Sm-F	846,99	1,575	2791,89	5,193	3638,88	6,768	1693,98	3,152	1944,9	3,618
Schr	29,25	0,054	1,35	0,003	30,6	0,057	2,7	0,006	27,9	0,051
Gr-L	1731,78	3,221	1646,73	3,063	3378,51	6,284	3293,46	6,126	85,05	0,158
Sa-P	7,11	0,013	0,63	0,001	7,74	0,014	1,26	0,002	6,48	0,012
Gr-An	2588,85	4,815	937,98	1,745	3526,83	6,560	1875,96	3,490	1650,87	3,070
Cro-L	2000,25	3,721	1463,31	2,722	3463,56	6,443	2926,62	5,444	536,94	0,999
Ero-L	17,46	0,032	4,86	0,009	22,32	0,041	9,72	0,018	12,6	0,023
Ur-U	138,24	0,257	2,16	0,004	140,4	0,261	4,32	0,008	136,08	0,253
Fl-P	36,54	0,068	134,73	0,251	171,27	0,319	73,08	0,136	98,19	0,183
S-Shr	6303,42	11,725	5447,43	10,132	11750,85	21,857	10894,86	20,264	855,99	1,593
Total	15568	28,956	15568	28,958	15568,02	28,957	12256,11	22,799	3311,91	6,16

Table 6. Landscape Dynamic in the Boconó River Basin for the Period T1 – T2 (1997-2008)

The third category experiencing changes in the period is Gr-An, with a value of 3526, 83 ha (6, 6% of total area) for total change. It had the second higher value for gains in the period (2588, 85 ha), meanwhile the losses (937, 98 ha), were lower in comparison to the last period. Of the total value, 1875, 96 ha changed in a swapping-change form. The fourth position in this period is for Cro-L, having a value of 3463, 56 ha (6, 4% of the total area). Cropland gained 2000, 25 ha (the 3rd highest value) during the period, losing 1463, 31 ha (5th value), which can be explained for the type of agriculture applied in the area (small/scale agriculture with shifting cultivation and slash and burn practices). This could explain the high value for swapping (2926, 62 ha) which is the third highest value for the period.

The Gr-L had a total change of 3378, 51 ha (6, 3% of total area), as the fifth changing category. It maintained the same trend as in the last period, gaining 1731, 78 ha, losing 1646, 73 ha, with 3293, 46 ha as swapping-change value. The sixth position in this period was for the Tmc-F, which showed a total change of 2901, 24 ha (5, 4% of the total area). It showed the same trend for gain as in the last period (877, 5 ha), but the losses were quite higher (2023, 74 ha), with 1755, 0 ha as swapping-change dynamic value.

Finally, the Oc-F descended to the seventh position in the period, showing a total change of 2103, 84 ha (3, 9% of the total area). It gained 990, 63 ha, and lost 1113,21 ha, with a swapping value of 1981, 26 ha for the period.

The dynamic showed by the net change values changed slightly respect the last period. The category with the highest net change value was Sm-F (1944, 9 ha), followed by Gr-An (1650, 87 ha); and the Tmc-F reached the third position, with a net change of 1146 ha. S-Shr descended to the fourth position with 855, 99 ha, followed by Cro-L (536, 94 ha) and Ur-U in the sixth position, with a net change value of 136, 08 ha (most of the change occurring as net change).

5.2.2. Systematic Inter-category transitions in the landscape system

Now is possible to derive the categorical trajectory of the changes which have been occurring in the river basin during the considered period. The Table 7 accounts for the most important inter-category transitions for T0-T1 in terms of Losses. The magnitude of the ratio (fifth column) indicates in all cases the strength of the systematic transition between categories [54].

The first thirteen rows on Table 7 indicate spatial patterns or transitions affecting the Forested Land Covers in the River Basin: Tmc-F, Oc-F and Sm-F. These transitions indicate changes associated with deterioration, decrease or disappearance of the Forested areas, depending on the LULC category for which the forested categories have been migrating during the period. For example, the first transition process: Tmc-F – Oc-F indicate that the Tropical Montane Cloudy Forest changed to Open-cleared Forest in 3,764 times more than would be expected If the change were to occur randomly, losing 348,65 ha more than the expected value. This transition, together with the second one, indicate that the TMCF is changing systematically to an intermediate stage (Open-cleared Forest or Successional Shrubland), before it can finally change or migrate to any human–induced types of Land Use categories (Gr-An or Cro-L). No transitions from Tmc-F to Land Use categories were observed. Similar transitional trends were observed in the Highlands of Chiapas – Mexico by [13] and [59], being also described in two different regions in Chile [60][61].

The processes driving the transitions of the Tmc-F are basically associated with: clearcutting, logging, wood extraction and also plants and non-wood extraction. These processes could have been occurring in a successive way, and particularly the logging is probably occurring in a selective form, as observed during the field validation. The selective extraction or harvesting of non-wood products (like Orchids and Bromeliads), has been also reported as a critical problem occurring in this ecosystem [9].

Another example is the transition Sm-F – Ero-L, indicating that in this portion of the surface area, the clearcutting/ logging processes derived in severe land degradation processes like erosion in 6,428 times more than expected, affecting 12, 33 ha. The rest of transitions contribute to explain the other change patterns occurring in the rest of categories, particularly in the human-induced types of Land Cover.

Sistematic Transition T0 »»»» T1	Ov	Ev	Ov-Ev	Ov-Ev/ Ev	Interpretation of the Transition
Tmc-F »»»» Oc-F	441,27	92,62	348,65	3,764	When Tropical Montane Cloudy Forest loses, Open-cleared Forest replaces it
Tmc-F »»»» S-Shr	1041,12	673,26	367,86	0,546	When Tropical Montane Cloudy Forest loses, Sucessional Shrubland replaces it
Oc-F »»»» Gr-An	168,93	57,19	111,74	1,954	When Open-cleared Forest loses, Grass Anthropogenic replaces it
Oc-F »»»» Cro-L	176,76	112,83	63,93	0,567	When Open-cleared Forest loses, Cropland replaces it
Oc-F »»»» S-Shr	1863,45	580,24	1283,21	2,212	When Open-cleared Forest loses, Sucessional Shrubland replaces it
Sm-F »»»» Oc-F	124,29	100,31	23,98	0,239	When Sub-montane Forest loses, Open-cleared Forest replaces it
Sm-F »»»» Gr-An	124,65	71,86	52,79	0,735	When Sub-montane Forest loses, Grass Anthropogenic replaces it.
Sm-F »»»» Cro-L	339,48	141,79	197,69	1,394	When Sub-montane Forest loses, Cropland replaces it. Cropland gains.
Sm-F »»»» Ero-L	12,33	1,66	10,67	6,428	When Sub-montane Forest loses, Eroded Land replaces it.
Sm-F »»»» Ur-U	61,92	44,37	17,55	0,396	When Sub-montane Forest loses, Urban Use replaces it. Urban Use gains.
Sm-F »»»» Fl-P	83,7	23,85	59,85	2,509	When Sub-montane Forest loses, Flooding Plain replaces it.
Sm-F »»»» S-Shr	2013,39	729,16	1284,23	1,761	When Sub-montane Forest loses, Sucessional Shrubland replaces it.
Schr »»»» S-Shr	1,35	0,31	1,04	3,355	When Schrubland loses, Sucessional Shrubland replaces it.
Gr-L »»»» Gr-An	174,33	46,24	128,09	2,770	When Grassland loses, Grass Anthropogenic replaces it.
Gr-L »»»» Cro-L	316,53	91,22	225,31	2,470	When Grassland loses, Cropland replaces it.
Gr-L »»»» Ur-U	31,32	28,54	2,78	0,097	When Grassland loses, Urban Use replaces it. Urban Use gains.
Gr-L »»»» Fl-P	31,32	15,34	15,98	1,042	When Grassland loses, Flooding Plain replaces it.
Gr-L »»»» S-Shr	1224,45	469,13	755,32	1,610	When Grassland loses, Sucessional Shrubland replaces it.
Sa-P »»»» S-Shr	3,78	0,86	2,92	3,395	When Sub Andean Páramo loses, sucessional Shrubland replaces it
Gr-An »»»» Oc-F	51,39	37,15	14,24	0,383	When Grass Anthropogenic loses, Open-cleared Forest replaces it.
Gr-An »»»» Gr-L	230,4	73,24	157,16	2,146	When Grass Anthropogenic loses, Grassland replaces it
Gr-An »»»» Cro-L	100,89	52,51	48,38	0,921	When Grass Anthropogenic loses, Cropland replaces it.
Gr-An »»»» S-Shr	706,68	270,02	436,66	1,617	When Grass Anthropogenic loses, Sucessional Shrubland replaces it.
Cro-L »»»» Sm-F	283,32	201,08	82,24	0,409	When Cropland loses, Sub-montane Forest replaces it.
Cro-L »»»» Gr-L	221,85	105,02	116,83	1,112	When Cropland loses, Grassland replaces it.
Cro-L »»»» Gr-An	70,11	38,16	31,95	0,837	When Cropland loses, Grass Anthropogenic replaces it.
Cro-L »»»» Ur-U	98,1	23,56	74,54	3,164	When Cropland loses, Urban Use replaces it.
Cro-L »»»» Fl-P	49,05	12,66	36,39	2,874	When Cropland loses, Flooding Plain replaces it
Cro-L »»»» S-Shr	846,63	387,19	459,44	1,187	When Cropland loses, Sucessional Shrubland replaces it.
Ero-L »»»» Tmc-f	7,74	6,58	1,16	0,176	When Eroded Land loses, Tropical Montane Cloudy Forest replaces it.
Ero-L »»»» Cro-L	1,35	0,65	0,70	1,077	When Eroded Land loses, Cropland replaces it.
Ero-L »»»» Fl-P	1,35	0,11	1,24	11,273	When Eroded Land loses, Fluvial Plain replaces it.
Ur-U »»»» Fl-P	0,72	0,01	0,71	71,000	When Urban Use loses, Flooding Plain replaces it.
Fl-P »»»» Gr-L	2,7	2,31	0,39	0,169	When Flooding Plain loses, Grassland replaces it.
Fl-P »»»» Cro-L	14,31	1,66	12,65	7,620	When Flooding Plain loses, Cropland replaces it.
Fl-P »»»» Ur-U	6,57	0,52	6,05	11,635	When Flooding Plain loses, Urban Use replaces it.
Fl-P »»»» S-Shr	11,43	8,53	2,90	0,340	When Flooding Plain loses, Sucessional Shrubland replaces it.
S-Shr »»»» Oc-F	513,0	170,58	342,42	2,007	When Sucessional Shrubland loses, Open-cleared Forest replaces it.
S-Shr »»»» Sm-F	984,69	643,94	340,75	0,529	When Sucessional Shrubland loses, Sub-montane Forest replaces it.
S-Shr »»»» Gr-L	811,44	336,32	475,12	1,413	When Sucessional Shrubland loses, Grassland replaces it.
S-Shr »»»» Gr-An	497,34	122,20	375,14	3,070	When Sucessional Shrubland loses, Grass Anthropogenic replaces it.
S-Shr »»»» Cro-L	766,53	241,11	525,42	2,179	When Sucessional Shrubland loses, Cropland replaces it.
S-Shr »»»» Ur-U	84,06	75,44	8,62	0,114	When Sucessional Shrubland loses, Urban Use replaces it.

Ov: Observed Value/ Ev: Expected Value

Table 7. The most systematic transitions occurred in T0-T1, in terms of Losses

As seen on Table 7, Gr-L is basically migrating to Gr-An (174, 33 ha), Cro-L (316, 53 ha) and S-Shr (1224, 45 ha), and with less importance, to Fl-P (31, 32 ha) and Ur-U (31, 32 ha), respectively. Gr-An is basically migrating to Gr-L in 2,146 times more than expected (230, 4 ha). This contributes to explain the high swapping value observed for Gr-L during the period. The category Cro-L migrated to Ur-U in 3,164 times more than expected (98, 1 ha); to Fl-P in 2,874 (49, 05 ha), and to S-Shr in 1,187 times more than expected (846, 63 ha). Particularly the transition Cro-L – Fl-P indicates that the hydrological dynamic of the river, especially the peak flows or flooding events, affected cropping areas. The transition Ero-L – Fl-P suggests an intense hydrological dynamic during the period, which augmented the sediments emission of the river. [62] determined that the yield of sediments in the whole catchment area have increased by 914 % with respect of the estimated value in order to build the Boconó-Tucupido Dam System, located dowmstreams in the lowland region.

The transition Ur-U – Fl-P also suggest that the hydrological events occurred during the period, affected the urban area of Boconó city, which had been expanding across the fluvial plain of the River; it can be corroborated some rows below, with the transition Fl-P – Ur-U, in which the urban area grew up across the Flooding Plain 11,625 times more than expected (6,57 ha). Important flooding events occurred in 1988, 1989, 1991 and 1995 were analyzed by [63]; unfortunately, the historical data for the River Basin is quite deficient and no more reference data exist since 1997.

Finally, the transitions for the category S-Shr suggest a trend for the category to migrate to the human-induced types of Land Cover categories Gr-An (3,070 times more than expected); Cro-L (2,179 times more than expected) and Ur-U (0,114 times more than expected). The rest of the transitions suggest a regeneration process. Shrubland was also observed as a highly dynamic category in the Kalu District-Ethiopia by [64], and also in Central Chile by [60], which can be explained by the forms of cultivation above mentioned, mostly typical in these regions.

The Table 8 shows the most systematic inter-category transitions occurred in the period T0 – T1 in terms of gain. The first twelve transitions are associated to changes in the Forested Land Covers. Particularly the transition Sm-F – Ero-L indicate erosion processes occurring after the clearcutting of the Sub-montane Forest, in 5,489 times more than expected, affecting a total of 12,33 ha. On the other hand, the transitions Gr-An – Gr-l (4,760); Gr-An – S-Shr (2,231), and Gr-An - Sm-F (0,232) suggest a regeneration/revegetation process.

As seen on Table 8, the cropland area in the river basin is growing at the expense of the categories: Oc-F (176, 76 ha), Sm-F (339, 48 ha), Gr-L (316, 53 ha), Gr-An (100, 89 ha), and S-Shr (766, 53 ha). On the other hand, the Gr-An gained surface area migrating basically from: Oc-F (168, 93 ha), Gr-L (174, 33 ha), Cro-L (70, 11 ha), and from S-Shr (497, 34 ha).

The transition Cro-L – Sm-F could to indicate regeneration, or perhaps a change to coffee plantation, or a combination of both scenarios. The transition Cro-L – Gr-L could be explained by the type of cultivation usually practiced in the area, above mentioned.

Sistematic Transition T0 »»»» T1	Ov	Ev	Ov - Ev	Ov–Ev / Ev	Interpretation of the Transition
Tmc-F »»»» Schr	58,32	27,49	30,83	1,121	When Schrub gains, it replaces the Tropical Montane Cloudy Forest
Tmc-F »»»» Sa-P	6,93	3,40	3,53	1,038	When Sub Andean Páramo gains, it replaces the Tropical Montane Cloudy Forest
Oc-F »»»» Sm-F	130,32	102,46	27,86	0,272	When the Sub-montane Forest gains, it replaces the Open-cleared Forest.
Oc-F »»»» Gr-L	149,31	92,90	56,41	0,607	When the Grassland gains, it replaces the Open-cleared Forest
Oc-F »»»» Gr-An	168,93	61,50	107,43	1,747	When Grass Anthropogenic gains, it replaces Open-cleared Forest
Oc-F »»»» Cro-L	176,76	103,19	73,57	0,713	When Cropland gains, it replaces the Open-cleared Forest
Oc-F »»»» S-Shr	1863,45	507,89	1355,5 6	2,669	When Sucessional Shrub gains, it replaces Open-cleared Forest
Sm-F »»»» Cro-L	339,48	261,07	78,41	0,300	When Cropland gains, it replaces the Sub-montane Forest
Sm-F »»»» Ero-L	12,33	1,90	10,43	5,489	When Eroded Land gains, it replaces the Sub-montane Forest
Sm-F »»»» Ur-U	61,92	41,75	20,17	0,483	When Urban Use gains, it replaces the Sub-montane Forest
Sm-F »»»» Fl-P	83,7	27,41	56,29	2,054	When Flooding Plain gains, it replaces the Sub-montane Forest
Sm-F »»»» S-Shr	2013,39	1284,98	728,41	0,567	When Sucessional Shrubland gains, it replaces the Sub-montane Forest
Gr-L »»»» Sm-F	136,08	126,21	9,87	0,078	When Sub-montane Forest gains, it replaces the Grassland
Gr-L »»»» Gr-An	174,33	75,76	98,57	1,301	When Grass Anthropogenic gains, it replaces Grassland
Gr-L »»»» Cro-L	316,53	127,11	189,42	1,490	When Cropland gains, it replaces Grassland
Gr-L »»»» Ur-U	31,32	20,33	10,99	0,541	When Urban use gains, it replaces Grassland
Gr-L »»»» Fl-P	31,32	13,35	17,97	1,346	When Flooding Plain gains, it replaces Grassland
Gr-L »»»» S-Shr	1224,45	625,63	598,82	0,957	When Sucessional Shrubland gains, it replaces Grassland
Gr-An »»»» Oc-F	51,39	30,21	21,18	0,701	When Open- cleared Forest gains, it replaces Grass Anthropogenic
Gr-An »»»» Sm-F	54,36	44,12	10,24	0,232	When Sub-montane Forest gains, it replaces Grass Anthropogenic
Gr-An »»»» Gr-L	230,4	40,00	190,40	4,760	When Grassland gains, it replaces Grass Anthropogenic
Gr-An »»»» Cro-L	100,89	44,43	56,46	1,271	When Cropland gains, it replaces Grass Anthropogenic
Gr-An »»»» Ur-U	9,72	7,10	2,62	0,369	When Urban Use gains, it replaces Grass Anthropogenic
Gr-An »»»» S-Shr	706,68	218,69	487,99	2,231	When Sucessional Srhubland gains, it replaces Grass Anthropogenic
Cro-L »»»» Sm-F	283,32	75,90	207,42	2,733	When Sub-montane Forest gains, it replaces Cropland
Cro-L »»»» Gr-L	221,85	68,82	153,03	2,224	When Grassland gains, it replaces Cropland
Cro-L »»»» Gr-An	70,11	45,56	24,55	0,539	When Grass Anthropogenic gains, it replaces Cropland
Cro-L »»»» Ur-U	98,1	12,22	85,88	7,028	When Urban Use gains, it replaces Cropland
Cro-L »»»» Fl-P	49,05	8,03	41,02	5,108	When Flooding Plain gains, it replaces Cropland
Cro-L »»»» S-Shr	846,63	376,26	470,37	1,250	When Sucessional Shrubland gains, it replaces Cropland
Ero-L »»»» Tmc-F	7,74	0,78	6,96	8,923	When Tropical Montane Cloudy Forest gains, it replaces Eroded Land
Ero-L »»»» Cro-L	1,35	0,99	0,36	0,364	When Cropland gains, it replaces Eroded Land
Ero-L »»»» Fl-P	1,35	0,10	1,25	12,500	When Flooding Plain gains, it replaces Eroded Land
Fl-P »»»» Cro-L	14,31	8,15	6,16	0,756	When Cropland gains, it replaces Flooding Plain
Fl-P »»»» Ur-U	6,57	1,30	5,27	4,054	When Urban Use gains, it replaces Flooding Plain
S-Shr »»»» Tmc-F	638,01	233,26	404,75	1,735	When Tropical Montane Cloudy Forest gains, it replaces Sucessional Shrubland
S-Shr »»»» Oc-F	513	202,72	310,28	1,531	When Open cleared Forest gains, it replaces Sucessional Shrubland
S-Shr »»»» Sm-F	984,69	296,05	688,64	2,326	When Sub-montane Forest gains, it replaces Sucessional Shrubland
S-Shr »»»» Gr-L	811,44	268,40	543,04	2,023	When Grassland gains, it replaces Sucessional Shrubland
S-Shr »»»» Gr-An	497,34	177,70	319,64	1,799	When Grass Anthropogenic gains, it replaces Sucessional Shrubland
S-Shr »»»» Cro-L	766,53	298,15	468,38	1,571	When Cropland gains, it replaces Sucessional Shrubland
S-Shr »»»» Ur-U	84,06	47,68	36,38	0,763	When Urban Use gains, it replaces Sucessional Shrubland

Ov: Observed Value/ Ev: Expected Value

Table 8. The most systematic transitions occurred in T0-T1, in terms of Gains

The fact that the urban areas have been growing at the expense of croplands is corroborated again with the transition Cro-L – Ur-U, which indicates that the urban areas grew up from

Cropland in 7,028 times more than expected (98,1 ha). The urban areas also grew up at the expense of other categories: Sm-F (61, 92 ha), Gr-L (31, 31 ha), S-Shr (84, 06 ha) and Gr-An (9, 72 ha). On the other hand, the Fl-P grew up at the expense of Cro-L in 5,108 times more than expected, affecting 49, 05 ha.

The transition Ero-L – Tmc-F suggest a regeneration/revegetation process, showing a high level of resilience for the TMCF to be regenerated after such disturbances like landslides, as in this case. The transition Ero-L - Fl-P focuses a source of sediments which were transported by the river during the period. On the other hand, the transition Fl-P – Ur-U confirms the fact that the urban areas (in this case, the urban area of Boconó city) is expanding through the Flooding plain. The last transitions help to confirm the higher swapping-change dynamic associated to the category S-Shr.

The Tables 9 and 10 resume the most systematic transitions occurred in the second period (T1 – T2) in terms of losses and gains, respectively.

As seen on Table 9, the number of rows accounting for changes in the Forested LC was reduced to 9, because of a slight reduction in the transitions of Sm-F, which explains the reduction in the swapping value observed in the category for this period.

The same trend in the transitions for the Tmc-F can be observed in this period, but additionally 5,31 ha of the area covered by the category was affected by erosion processes, particularly landslides. An incipient transition process for the Sa-P occurred during the period, suggesting that some changes derived by anthropogenic pressure have been occurring in the Páramo ecosystems of the river basin. The growing anthropogenic pressure over the Sub-Andean Páramo in the study area was already reported by [65].

The categories Gr-L, Gr-An and Cro-L show the same transitional trends as in the last period. The Urban use continued to growing up at the expense of croplands and the flooding plain, and at the same time, the urban area continued being affected by peak flows or flooding processes. Finally, the S-Shr showed migrating trends to Gr-An (3,168), Cro-L (1,719), to Gr-L (1,507) and to Oc-F (0,910) also.

Respect to the gains in this period, the Table 10 illustrates the trend, where the first ten rows show the changes affecting the Forested LCC. In general, the trends and patterns for the transitions observed on last period remain during the second period.

The category Gr-L showed less intensity in the swapping, meanwhile Cro-L gained surface at the expense of Oc-F (66, 78 ha), Sm-F (269, 37 ha), Gr-L (361, 17 ha), Gr-An (172, 44 ha), Fl-P (36, 9 ha) and S-Shr (1037, 97 ha). Gr-An gained surface migrating from Gr-L in 2,142 times more than expected (502, 83 ha), and also from Cro-L (213, 39 ha), and from S-Shr (1571, 40 ha).

The urban areas continued to growing up in the period, gaining surface area basically from Sm-F (43, 38 ha), Gr-An (3, 78 ha), Cro-L (46, 08 ha), Fl-P (5, 85 ha) and S-Shr (31, 95 ha). Particularly the urban area growing close or into the category Fl-P is vulnerable to the river dynamic. During this period the category S-Shr reported systematic transitions with all the rest of the categories, which explain the high value for swapping-change for the category in this period.

Systematic Transition T1 »»»» T2	Ov	Ev	Ov - Ev	Ov–Ev / Ev	Interpretation of the Transition
Tmc-F »»»» Oc-F	470,07	98,89	371,18	3,753	When Tropical Montane Cloudy Forest loses, Open-cleared Forest replaces it.
Tmc-F »»»» Ero-L	5,31	2,58	2,73	1,058	When Tropical Montane Cloudy Forest loses, Eroded Land replaces it.
Tmc-F »»»» S-Shr	1335,15	832,04	503,11	0,605	When Tropical Montane Cloudy Forest loses, Sucessional Shrubland replaces it.
Oc-F »»»» Gr-An	77,13	60,35	16,78	0,278	When Open-cleared Forest loses, Grass Anthropogenic replaces it.
Oc-F »»»» Cro-L	66,78	61,11	5,67	0,093	When Open-cleared Forest loses, Cropland replaces it.
Oc-F »»»» S-Shr	900,0	273,65	626,35	2,289	When Open-cleared Forest loses, Sucessional Srhubland replaces it.
Sm-F »»»» Cro-L	269,37	161,78	107,59	0,665	When Sub-montane Forest loses, Cropland replaces it.
Sm-F »»»» Ero-L	3,15	2,25	0,90	0,400	When Sub-montane Forest loses, Eroded Land replaces it.
Sm-F »»»» S-Shr	2122,38	724,49	1397,89	1,929	When Sub-montane Forest loses, Sucessional Shrubland replaces it.
Schr »»»» Gr-An	0,18	0,07	0,11	1,571	When Schrubland loses, Grass Anthropogenic replaces it.
Schr »»»» Ero-L	0,72	0,001	0,72	719,000	When Schrubland loses, Eroded Land replaces it.
Schr »»»» S-Shr	0,45	0,33	0,12	0,364	When Schrubland loses, Sucessional Shrubland replaces it.
Gr-L »»»» Gr-An	502,83	92,48	410,35	4,437	When Grassland loses, Grass Anthropogenic replaces it.
Gr-L »»»» Cro-L	361,17	93,64	267,53	2,857	When Grassland loses, Cropland replaces it.
Gr-L »»»» S-Shr	696,15	419,33	276,82	0,660	When Grassland loses, Sucessional Shrubland replaces it.
Sa-P »»»» Schr	0,36	0,01	0,35	35,000	When Sub-andean Páramo loses, Schrubland replaces it.
Sa-P »»»» Gr-An	0,18	0,03	0,15	5,000	When Sub-andean Páramo loses, Grass Anthropogenic replaces it.
Gr-An »»»» Gr-L	124,29	61,43	62,86	1,023	When Grass Anthropogenic loses, Grassland replaces it.
Gr-An »»»» Cro-L	172,44	52,81	119,63	2,265	When Grass Anthropogenic loses, Cropland replaces it.
Gr-An »»»» S-Shr	557,19	236,49	320,70	1,356	When Grass Anthropogenic loses, Sucessional Shrubland replaces it.
Cro-L »»»» Sm-F	161,73	123,04	38,69	0,314	When Cropland loses, Sub-montane Forest replaces it.
Cro-L »»»» Gr-L	266,58	95,91	170,67	1,779	When Cropland loses, Grassland replaces it.
Cro-L »»»» Gr-An	213,39	81,43	131,96	1,621	When Cropland loses, Grass Anthropogenic replaces it.
Cro-L »»»» Ero-L	1,89	1,15	0,74	0,643	When Cropland loses, Eroded Land replaces it.
Cro-L »»»» Ur-U	46,08	24,88	21,20	0,852	When Cropland loses, Urban Use replaces it.
Cro-L »»»» Fl-P	10,08	8,45	1,63	0,193	When Cropland loses, Flooding Plain replaces it.
Cro-L »»»» S-Shr	656,55	369,19	287,36	0,778	When Cropland loses, Sucessional Shrubland replaces it.
Ero-L »»»» Sm-F	1,89	0,39	1,50	3,846	When Eroded Land loses, Sub-montane Forest replaces it.
Ero-L »»»» Cro-L	0,9	0,26	0,64	2,462	When Eroded Land loses, Cropland replaces it.
Ero-L »»»» Fl-P	0,45	0,03	0,42	14,000	When Eroded Land loses, Flooding Plain replaces it.
Ero-L »»»» S-Shr	1,53	1,16	0,37	0,319	When Eroded Land loses, Sucessional Shrubland replaces it.
Ur-U »»»» Fl-P	2,16	0,01	2,15	215,000	When Urban Use loses, Flooding Plain replaces it.
Fl-P »»»» Sm-F	41,31	10,78	30,53	2,832	When Flooding Plain loses, Sub-montane Forest replaces it.
Fl-P »»»» Gr-L	11,16	8,41	2,75	0,327	When Flooding Plain loses, Grassland replaces it.
Fl-P »»»» Cro-L	36,9	7,23	29,67	4,104	When Flooding Plain loses, Cropland replaces it.
Fl-P »»»» Ero-L	0,18	0,10	0,08	0,800	When Flooding Plain loses, Eroded Land replaces it.
Fl-P »»»» Ur-U	5,85	2,18	3,67	1,683	When Flooding Plain loses, Urban Use replaces it.
Fl-P »»»» S-Shr	33,93	32,36	1,57	0,049	When Flooding Plain loses, Sucessional Shrubland replaces it.
S-Shr »»»» Oc-F	387,99	203,17	184,82	0,910	When Sucessional Shrubland loses, Open-cleared Forest replaces it.
S-Shr »»»» Gr-L	1113,21	444,05	669,16	1,507	When Sucessional Shrubland loses, Grassland replaces it.
S-Shr »»»» Gr-An	1571,4	377,00	1194,40	3,168	When Sucessional Shrubland loses, Grass Anthropogenic replaces it.
S-Shr »»»» Cro-L	1037,97	381,71	656,26	1,719	When Sucessional Shrubland loses, Cropland replaces it.
S-Shr »»»» Ero-L	6,12	5,31	0,81	0,153	When Sucessional Shrubland loses, Eroded Land replaces it.

Ov: Observed Value/ Ev: Expected Value

Table 9. The most systematic transitions occurred in T1-T2, in terms of Losses

Sistematic Transition T1 »»»» T2	Ov	Ev	Ov - Ev	Ov–Ev / Ev	Interpretation of the Transition
Tmc-F »»»» Oc-F	470,07	450,06	20,01	0,044	When Open-cleared Forest gains, it replaces Tropical Montane Cloudy Forest.
Tmc-F »»»» Schr	14,67	13,18	1,49	0,113	When Schrubland gains, it replaces Tropical Montane Cloudy Forest.
Tmc-F »»»» Sa-P	3,33	3,20	0,13	0,041	When Sub-andean Páramo gains, it replaces Tropical Montane Cloudy Forest.
Oc-F »»»» Cro-L	66,78	64,12	2,66	0,041	When Croppland gains, it replaces Open-cleared Forest.
Oc-F »»»» S-Shr	900,0	248,77	651,23	2,618	When Sucessional Shrubland gains, it replaces Open-cleared Forest.
Sm-F »»»» Cro-L	269,37	242,07	27,30	0,113	When Cropland gains, it replaces Sub-montane Forest.
Sm-F »»»» Ero-L	3,15	2,02	1,13	0,559	When Eroded Land gains, it replaces Sub-montane Forest.
Sm-F »»»» Ur-U	43,38	16,22	27,16	1,674	When Urban Use gains, it replaces Sub-montane Forest.
Sm-F »»»» Fl-P	6,39	4,26	2,13	0,500	When Flooding Plain gains, it replaces Sub-montane Forest.
Sm-F »»»» S-Shr	2122,38	939,10	1183,28	1,260	When Sucessional Shrubland gains, it replaces Sub-montane Forest.
Schr »»»» Ero-L	0,72	0,39	0,33	0,846	When Eroded Land gains, it replaces Schrubland
Gr-L »»»» Gr-An	502,83	160,05	342,78	2,142	When Grass Anthropogenic gains, it replaces Grassland.
Gr-L »»»» Cro-L	361,17	126,42	234,75	1,857	When Cropland gains, it replaces Grassland.
Gr-L »»»» Fl-P	3,6	2,23	1,37	0,614	When Flooding Plain gains, it replaces Grassland.
Gr-L »»»» S-Shr	696,15	490,47	205,68	0,419	When Sucessional Shrubland gains, it replaces Grassland.
Gr-An »»»» Tmc-F	40,5	34,45	6,05	0,176	When Tropical Montane Cloudy Forest gains, it replaces Grass Anthropogenic
Gr-An »»»» Sm-F	23,85	21,04	2,81	0,134	When Sub-montane Forest gains, it replaces Grass Anthropogenic
Gr-An »»»» Gr-L	124,29	40,50	83,79	2,069	When Grassland gains, it replaces Grass Anthropogenic
Gr-An »»»» Cro-L	172,44	45,94	126,50	2,754	When Cropland gains, it replaces Grass Anthropogenic
Gr-An »»»» Ur-U	3,78	3,08	0,70	0,227	When Urban Use gains, it replaces Grass Anthropogenic
Gr-An »»»» S-Shr	557,19	178,21	378,98	2,127	When Sucessional Shrubland gains, it replaces Grass Anthropogenic
Cro-L »»»» Tmc-F	78,03	67,97	10,06	0,148	When Tropical Montane Cloudy Forest gains, it replaces Cropland
Cro-L »»»» Sm-F	161,73	41,52	120,21	2,895	When Sub-montane Forest gains, it replaces Cropland
Cro-L »»»» Gr-L	266,58	79,90	186,68	2,336	When Grassland gains, it replaces Cropland
Cro-L »»»» Gr-An	213,39	114,74	98,65	0,860	When Grass Anthropogenic gains, it replaces Cropland
Cro-L »»»» Ero-L	1,89	0,76	1,13	1,487	When Eroded Land gains, it replaces Cropland
Cro-L »»»» Ur-U	46,08	6,07	40,01	6,591	When Urban Use gains, it replaces Cropland
Cro-L »»»» Fl-P	10,08	1,60	8,48	5,300	When Flooding Plain gains, it replaces Cropland
Cro-L »»»» S-Shr	656,55	351,62	304,93	0,867	When Sucessional Shrubland gains, it replaces Cropland
Ero-L »»»» Sm-F	1,89	0,49	1,40	2,857	When Sub-montane Forest gains, it replaces Eroded Land.
Ero-L »»»» Fl-P	0,45	0,02	0,43	21,500	When Flooding Plain gains, it replaces Eroded Land.
Ur-U »»»» Fl-P	2,16	0,50	1,66	3,320	When Flooding Plain Gains, it replaces Urban Use.
Fl-P »»»» Sm-F	41,31	6,98	34,33	4,918	When Sub-montane Forest gains, it replaces Flooding Plain.
Fl-P »»»» Cro-L	36,9	15,24	21,66	1,421	When Cropland gains, it replaces Flooding Plain.
Fl-P »»»» Ero-L	0,18	0,13	0,05	0,385	When Eroded Land gains, it replaces Flooding Plain.
Fl-P »»»» Ur-U	5,85	1,02	4,83	4,735	When Urban Use gains, it replaces Flooding Plain.
S-Shr »»»» Tmc-F	705,42	349,55	355,87	1,018	When Tropical Montane Cloudy Forest gains, it replaces Sucessional Shrubland.
S-Shr »»»» Oc-F	387,99	227,82	160,17	0,703	When Open-cleared Forest gains, it replaces Sucessional Shrubland.
S-Shr »»»» Sm-F	562,95	213,53	349,42	1,636	When Sub-montane Forest gains, it replaces Sucessional Shrubland.
S-Shr »»»» Schr	13,59	6,67	6,92	1,037	When Schrubland gains, it replaces Sucessional Shrubland.
S-Shr »»»» Gr-L	1113,21	410,90	702,31	1,709	When Grassland gains, it replaces Sucessional Shrubland.
S-Shr »»»» Sa-P	3,78	1,62	2,16	1,333	When Sub-andean Páramo gains, it replaces Sucessional Shrubland.
S-Shr »»»» Gr-An	1571,4	590,08	981,32	1,663	When Grass Anthropogenic gains, it replaces Sucessional Shrubland.
S-Shr »»»» Cro-L	1037,97	466,10	571,87	1,227	When Cropland gains, it replaces Sucessional Shrubland.
S-Shr »»»» Ero-L	6,12	3,95	2,17	0,549	When Eroded Land gains, it replaces Sucessional Shrubland.
S-Shr »»»» Ur-U	31,95	31,24	0,71	0,023	When Urban Use gains, it replaces Sucessional Shrubland.
S-Shr »»»» Fl-P	13,05	10,66	2,39	0,224	When Flooding Plain gains, it replaces Sucessional Shrubland.

Ov: Observed Value/ Ev: Expected Value

Table 10. The most systematic transitions occurred in T1-T2, in terms of Gains

6. Implications of the observed LULC changes for the watershed management and land use planning

The dynamic of the LULC in the Boconó River Basin for the considered period and through the approach used in this project, lead to establish key elements and a support basis to be considered in the planning processes at the watershed level or even at regional planning level also. Considering that the Boconó River Basin constitute a double "**Protected Area**", which has a paramount importance for the development of the water resources in the lowlands, the evaluation of LULC change under the ecosystem approach represent a innovative variation respect the traditional LULC evaluations, in which the LULC are usually considered categories in an abstract sense. In this case, the Land Cover categories are essentially valuable ecosystems which have an ecological richness as well as complementary environmental attributes, being very important to the conservation and sustainability of the three basic land resources: water, soils and biodiversity.

The systematic transitions show the trajectory or directionality of the changes in a categorical sense, leading to identify not only the categories which are more dynamic in a spatial-temporal perspective, but also the possible biophysical and anthropogenic processes driving the transitions. When both interpretations are correctly established, they simply lead to define the key elements to be considered in the land planning processes:

a. the way how the land resources have been used in the river basin during the last twenty years
b. the form how the land cover categories as ecosystems have been affected
c. the trends existing for the different Land Use/Land Cover categories, in a spatial/temporal perspective.

Particularly the spatial visualization (geographical visualization) results in a undoubtedly helpful tool for the planning process, allowing to perceive how these trends are spatially occurring, where are occurring specific processes accounted for problems to be solved, and where these problems are more diverse or intense (hot spots).

As an example, the Figure 3 show the geographic visualization of the transitions for the three main forested Land Cover Categories (LCC) (Tmc-F, Oc-F and Sm-F), for the period T0-T1. The transitions occurred during the Period T1-T2 are displayed on Figure 4. A simple observation of the maps, based on the systematic transitions above described, can lead to the following statements:

1.- The changes affecting the forested land covers, particularly the Tcm-F and the Sm-F tends to be produced in the boundary area between categories. The same trend was observed by [30] in Ecuador. This lead to define belts of clearcutting / logging, which are also called "**hot fronts**" of deforestation [9], being more evident for the categories: Tcm-F and Oc-F. In the Sub-montane Forest, the belts or "**hot fronts**" are not clearly defined, because this land cover is highly fragmented among the area. The "Río Negro" Sector located at the upper Boconó River (Figure 4) was severely affected by the changes on the three types of LC, indicating that the processes: clearcutting, logging, wood extraction and non wood & plant extractions were more intense in this sector, during the period. The sector could be defined as "**hot spot**" or "**red flag area**", considering that the deforestation and the LC change is occurring in the sector where the most important streams-sources of the river are located. This sector covers almost the 40% of the stream network area, having therefore the greatest water yield [42].

2.- Observing the two maps, is evident that in the first period, the Open-cleared Forest was systematically reduced among the river basin, meanwhile in the second period, the transition of the Tropical Montane Cloudy Forest was clearly spatially intensified. This lead to corroborate the fact that the dynamic of the TMCF is characterized by a systematic and progressive change, in which the category is migrating to an "intermediate" stage or LCC like Open-cleared Forest or Successional Shrubland, and in other successive stage it can to migrate to another LC or LU categories.

3.- Although the "Guaramacal National Park" was created on 1988, covering the flank south-east of the river basin [41], a "**hot front**" of deforestation can be observed in the inferior border of this protected area (Figure 3), which clearly increased during the second period (Figure 4). This fact reveals that the creation of the Park has not been completely effective in the protection of the ecosystems included in the protected area.

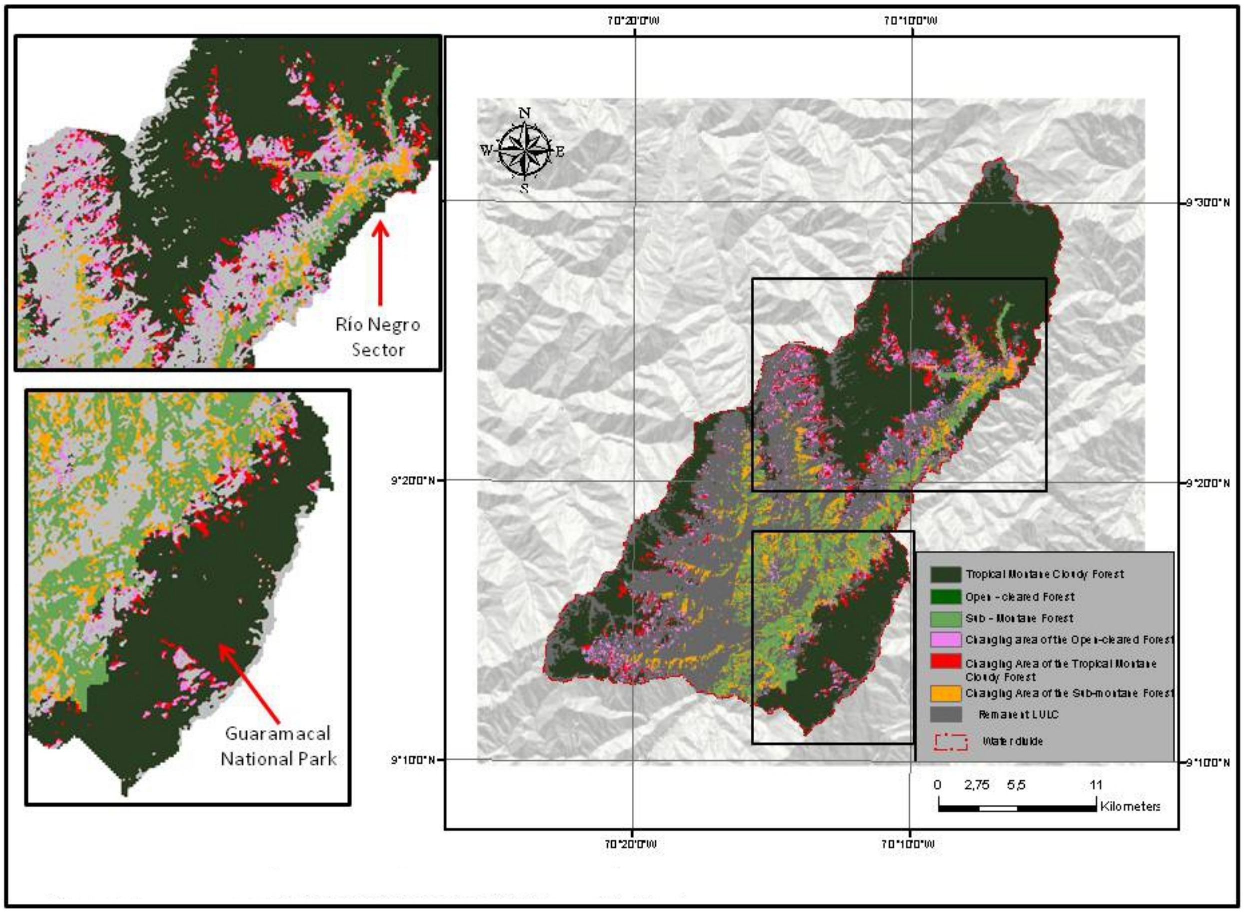

Figure 3. Transition area for the Forested Categories in the period T0-T1

4.- The transitions Sm-F – Fl-P; Cro-L – Fl-P and Ur-U – Fl-P suggests a relevant hydrological dynamic occurring during the period studied. The LC Flooding Plain changed actively on last 20 years, accounting for important events like peak flows or even flash-floodings, which expanded the limits of the category among the area, affecting other categories like Sm-F, Cro-L and Ur-U. The dynamic accounted for the Forested LC and the increase of cultivated soils and grass could have been playing a role in the intensification of the hydrological events. The ecological conditions, and particularly the type and density of the land cover play a very important role in the hydrological behaviour and the hydrological response of the landscape. Many authors like: [9] [36] [38] [66] [67] [68] and [69] have been highlighting the importance of the forest ecosystems in the hydrological patterns. Particularly the TMCF is considered as "**producer-water forest**", playing a paramount role in the rainfall dynamic, as well as the transpiration, interception, water budget and streamflows [9] [38]. Thus, the systematic reduction of this kind of forest may significantly reduce the rainfall interception, probably leading to an even higher streamflow in the area.

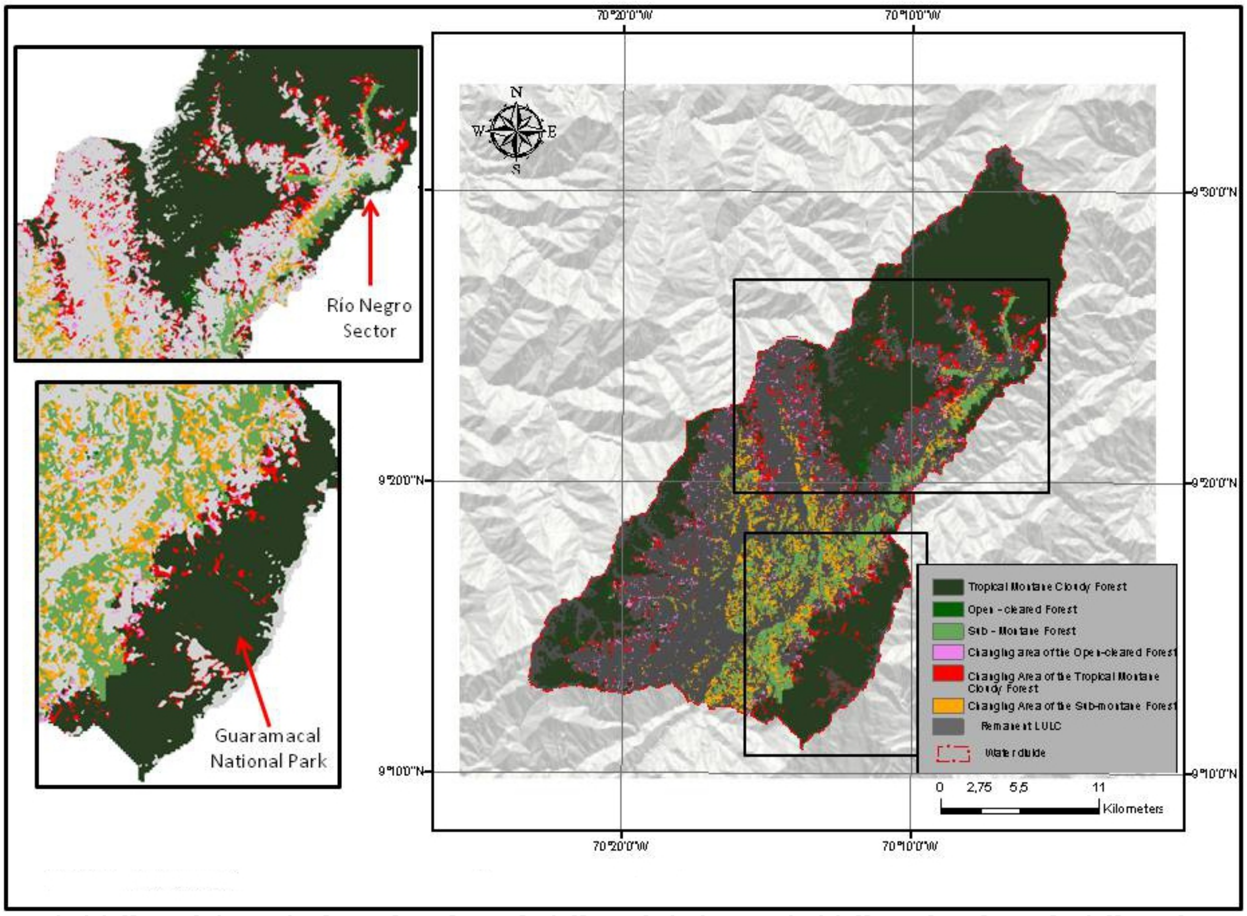

Figure 4. Transition area for the Forested Categories in the period T1-T2

5.- The transitions Sm-F – Ero-L; S-Shr – Ero-L; and Cro-L – Ero-L, indicate that the area is highly susceptible to soil degradation processes like sheet erosion, rill erosion, landslides and so on, processes which have been activating through the migration of Forested LCC to other categories like Cro-L. Only intense erosive processes like landslides were observed in the classification. However, [39] identified severe erosion processes, especially sheet erosion, in the San Miguel and San Rafael Watersheds (within the study area), which are spatially extended due the high accessibility (intricate road network), the fragile soils and the highly jointed bedrocks.

The accessibility (roads network) has been considered as one of the most important and critical drivers facilitating the LULC change in many regions worldwide [1] [39] [57] [67]

[70] [71] [72]. With the exception of the “Río Negro” Sector (See Figure 3), the Boconó River Basin presents a moderately high accessibility [43] [45] [63]. The results obtained by [39] in San Miguel / San Rafael watersheds through a regression tree analysis, revealed that the accessibility had the greatest level of contribution in the occurrence of soil erosion in the area, being the sectors where the cropland have been progressively expanding during the last decades. The occurrence of erosion processes was directly associated to the distance to the road network. This suggest that the accessibility could play a determinant role explaining the intensity and spatiality of the changes that the LULC have been experiencing in the River Basin, as demonstrated by studies conducted in other regions [1] [57] [70-72]. Due the nature and complexity of the variables usually involved, a rigorous analysis of the drivers of LULC change in the area was out of scope of this project, so that further research in this subject is strictly necessary in the near future, in order to comprehensively determine the causal relationship of the factors influencing the changes that affect the River Basin.

The Figures 5 and 6 show the transitions occurred in the Land Use Categories during the first and the second period, respectively. It can be clearly observed where the LUC grow up more intensively in the two periods. The superior window show the San Miguel – San Rafael Watersheds, the sectors where the croplands and the grass anthropogenic grew up more intensively for both periods. These are the sectors which have the most relevant problems related with land degradation in the area, as studied by [39]. The inferior window

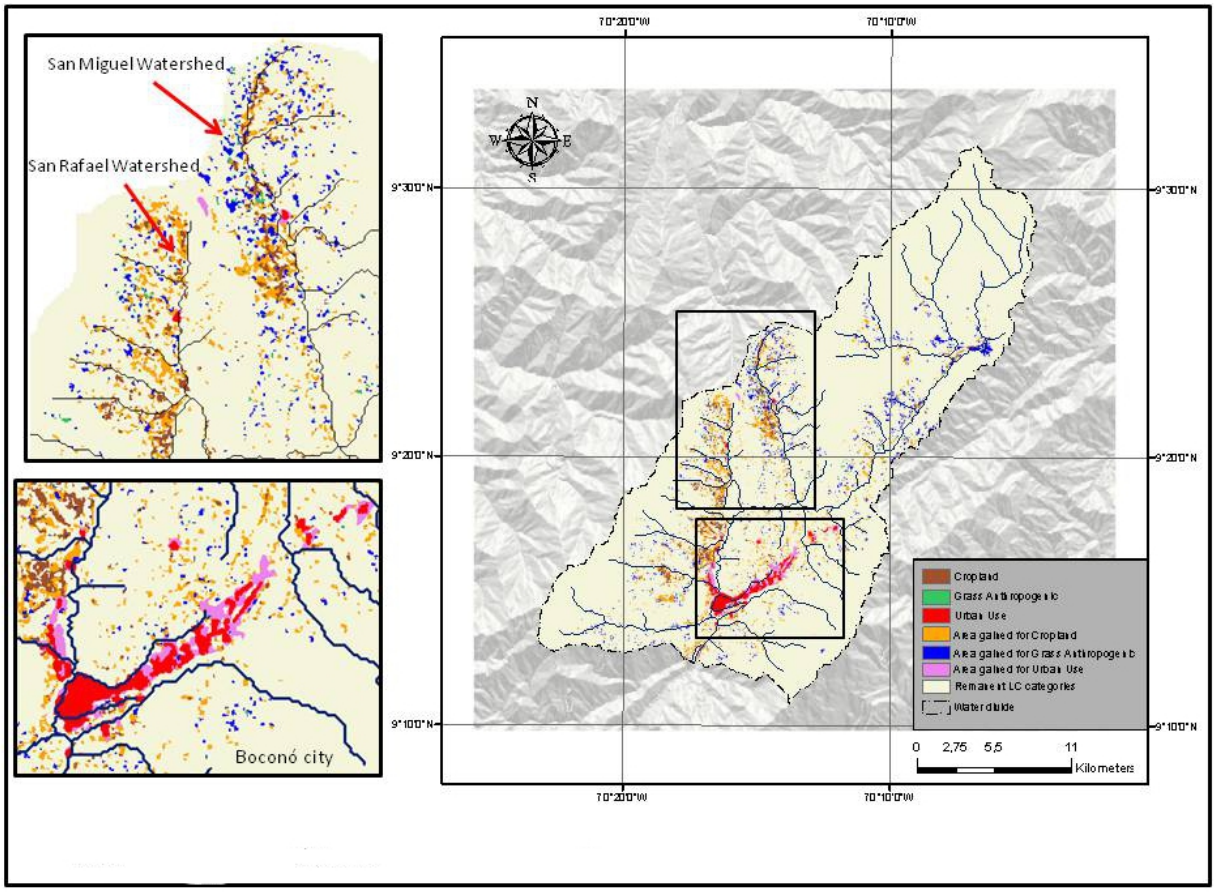

Figure 5. Transition area for the Land Use categories in the period T0-T1

show the expanding process that the Boconó city experienced during the two periods, showing how the city has been expanding among the flooding plain, in areas susceptible to be flooded. The transition Ur-U – Fl-P clearly indicates that some urban sectors have been damaged during the two periods analyzed.

All these interpretations constitutes important tools having practical importance for the institutions or stakeholders involved with the environmental and land planning at local/regional level, being a rational basis to design new plans, or even to improve those which already exists, in order to guaranty the optimization of the natural resource uses in the river basin. This is very important to encourage the effectiveness of the protective figures defined for the whole river basin, accounting for a more sustainable evolution of the LULC in this important "**water resource area**".

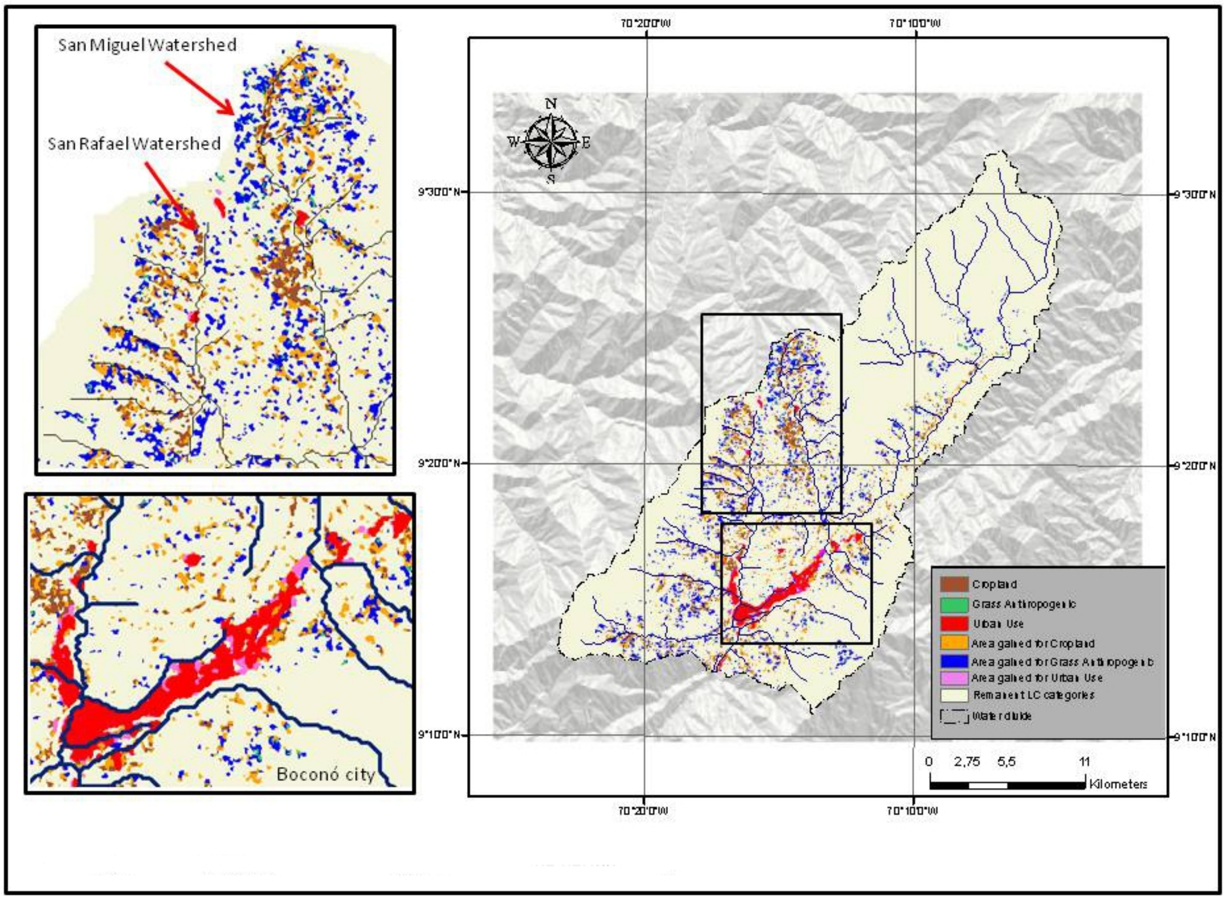

Figure 6. Transition area for the Land Use categories in the period T1-T2

7. Conclusions

The methodological approach combining the multitemporal LULC evaluation, together with the ecosystem approach and the inter-category transitional method, represented a very useful tool to define, to describe an to analyze the LULC system in the Boconó River Basin and the changes occurred in the last 20 years. The study demonstrated that the categories: Successional Srhubland (S-Shr), Sub-montane Forest (Sm-F), Open-cleared Forest (Oc-F) and

Cropland (Cro-L) were the most dynamic among the two considered periods, accounting for the highest total change value, as well as gains, losses, swapping and net change.

The study also demonstrated that the changes and the reduction showed by the Tropical Montane Cloudy Forest in the area, cannot be directly associated to the expansion of land use categories like Cropland or Grass Anthropogenic. At least on the last 20 years, the TMCF have been changing to an intermediate condition for LC, basically to Open-cleared Forest (Oc-F) and Sucessional Srhubland (S-Shr). Even when the TMCF is under anthropogenic pressure, it can be only associated with logging, wood and timber extraction, as well as the extraction of non wood products and plants.

The systematic transitions that have been occurring in the LULC categories reveal that the land uses Cropland (Cro-L) and Grass Anthropogenic (Gr-An) have been growing, gaining surface basically from Sucessional Shrubland (S-Shr), Sub-montane Forest (Sm-F), and Grassland (Gr-L).This justify the higher values for swapping-change, observed in these categories. On the other hand, the urban areas (Ur-U) have been growing basically at the expense of Cro-L, Gr-L and Fl-P.

The systematic transitions Sm-F – Fl-P; Cro-L – Fl-P and Ur-U – Fl-P, as well as the variation of the category Fl-P during the period, suggest an intense dynamic of the river, and the occurrence of high peak flows and important flooding events during the period, which have been affecting the urban expanding area, as well as croplands. Probably, the decrease of the forested areas, and particularly the TMCF, as well as the increase of the croplands and the grass-anthropogenic, could be directly affecting the hydrological dynamic in the river basin, particularly the behavior of the seasonal flows.

Finally, the systematic transitions helped to focus specific processes that suggest the existence of problems which need to be solved into the land use planning or the watershed management processes. The "**hot fronts**" of deforestation could be considered as critical areas or priority areas in order to promote the conservation/preservation of the valuable ecosystems as the TMCF, helping to define "**area-oriented policies**" to ensure the water resources management in the river basin.

Further rigorous research about the associated drivers for LULC change in the area is strictly necessary, in order to reach a comprehensive understanding of the dynamic and transitions of the LULC categories identified and characterized in this project, seeking to encourage the future decisions for land use planning within the watershed management at regional and local level.

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